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(71) Applicant: **D-Tech GmbH Antriebstechnik and Mikroelektronik**
33689 Bielefeld (DE)

(72) Inventor: **Gabriel, Rupprecht 33689 Bielefeld (DE)**

(74) Representatives: **Leonhard, Frank Reimund, Dipl.-Ing. et al**
Leonhard - Olgemaller - Fricke
Patentanwalte
Josephspitalstrasse 7
80331 Munchen (DE)

(54) Soldering semiconductor chips

(57) The invention relates to a process for soldering semiconductor chips (1) having a surface area to a substrate (20), wherein by means of a vacuum (V2) in a soldering area (30) an upper part (3) is mechanically centered and moved in relation to a lower part (4) while the substrate (20) is arranged on the lower part (4), and - one or more - chips (1) are held in a sidestable manner and pressed into the heated solder (9,10), as well as an apparatus for conducting said process.

Moreover, a soldering material for attaching large semiconductor chips, in particular power semiconductors (1), is provided, one soldering component (9) that melts at a melting temperature and a plurality of granules (10) that are resistant in relation to the soldering component and have a melting temperature that is higher than the melting temperature of the soldering component (9).

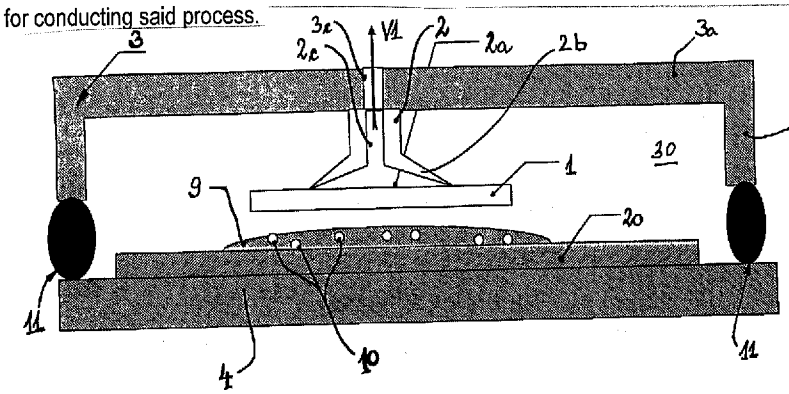

Fig. 1

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Description

The technical field of the invention is soldering processes for the attachment of in particular large semiconductor chips (e.g. power semiconductors) on substrates, as described in the DE-A 44 17 285 (Finetech).

By public prior use, known processes for soldering or attaching of power semiconductors are:

1. Reflow soldering with soldering paste and aggressive soldering flux, if necessary, also supplemented by silver or copper particles that are, according to EP-A 110,307 (Burroughs) referring to page 10, lines 1 to 20, melted at higher temperatures in order to provide for an additional metallization of the contact areas during soldering.

2. Forming of a eutectic bond connection under vacuum as in EP-A 361 715 (UCLA), wherein the bond connection comprises a layer thickness of only less than 10 micrometers. As connecting counterparts a silicon chip and a silicon substrate are provided, wherein a thin gold layer is inserted between the silicon chip and the silicon substrate and pressed with high pressure under vacuum, and additionally heating up approximately 400 degrees Celsius is planned (see there page 3, lines 28 to 33, page 4, lines 11 to 14 and 20 to 22 as well as claims 3 and 8).

3. Mere inserting of the chips into a liquid solder.

Large semiconductor chips (power semiconductors) must be well cooled. For this purpose they are soldered into metallic casings, on printed circuit boards with metallic core, thick-film circuits on ceramic substrates or DCB (Direct Copper Bonding) substrates. The main difficulty in the soldering of large semiconductors (edge length larger than 4mm) is to provide a cavity free soldering in combination with a defined layer thickness of the solder and to achieve a high positioning accuracy that might be affected by floating of the chips on the solder, said the positioning accuracy being required for achieving a high packing density. In today's integrated frequency converters between 18 and approx. 100 power semiconductors are located on one substrate. The quality of the soldering process and its reproducibility are of great importance for the quality of the product. Even a small amount of cavities can render the entire circuit with a high percentage useless or susceptible to trouble or failure.

The object of the invention is to increase the positioning accuracy of the chips during the soldering process. This is achieved according to claim 1 or claim 10.

The safety and accuracy of the soldering process are improved according to the invention by conducting the soldering process in a vacuum into the liquid solder and holding the chips side stably while the chips are pressed by the gradually increasing vacuum towards the carrier to be soldered to (the substrate) (claim 1). The method renders a safe and cavity free soldering possible also in case of a substrate carrying many chips. The chips are no

longer "floating" on the solder. The method can be automated easily, since no batch processes are necessary, and it can easily be integrated into placement machines and bonding machines. The cycle times are short.

The layer thickness adjustment of the solder is achieved by balls in the solder that have a higher melting temperature as the soldering temperature (claim 14). By means of a forced very fast cooling, the grain formation and thus the cycle firmness can be improved during the solidification of the solder (claim 5).

An apparatus for carrying out the process mentioned above (claim 10) consists of an upper part (designed as a lid or cover) and side stable receiving means for receiving the chips in their feeding position, a lower part (designed as a heating plate), at least one vacuum connection, a gas connection for cooling and a flexible sealing system between the upper part and the lower part that is temperature-proof and resilient for allowing a relative movement between the upper part and the heating plate. A further gas connection for flushing with inert gas can be provided (claim 13).

The volume of the soldering area is small (claim 12). In lateral direction, the chips are held and laterally guided under vacuum by suction units or a mat comprising holes (claim 11).

The field where the invention finds utility is in the field of soldering power semiconductors and large chips with high

energy dissipation, in particular in multi-chip systems, onto a substrate also called "circuit board".

Vacuum soldering processes according to numeral 2, mentioned at the outset, take place in the batch processing. The soldering times are very long. The results with regard to the solder layer thicknesses are inaccurate and not safely reproducible. The chips float on the solder and therefore the positioning accuracy is reduced. By means of the invention both the process stability is increased, as well as the consistency of the properties of soldering clearly improves. A side effect is a lower energy consumption result as compared to conventional soldering machines, despite a substantially reduced process time. The invention makes it possible to observe a multiplicity of parameters, like the components and the mixture of the pastes, the application of the soldering paste and the temperature profile of the surfaces.

The layer thickness of the solder can be guaranteed by means of solid particles of a defined size within the melted solder (claim 14). Such components can for instance be copper balls as used in a sintering process. Also, silicon globules are suitable because of their adapted expansion as compared to the soldering partner. For this purpose a small percentage of "spacers" are integrated into the solder (e.g. copper balls). In order to receive an even layer thickness, at least three solid spacers should be provided underneath each of the chips to be soldered. The upper limit is determined by the fact that it must be possible to compress the solder to a layer only having one

layer of spacers. Favorable ratios are 10% to 20% of solid components in the solder (claim 17). The properties of the solder can be positively adjusted by mixing in an appropriate amount of suitable materials into the solder.

The invention is described and supplemented in the following on the basis of several embodiments.

Figure 1 schematizes the starting point of a soldering process between a chip 1 and a substrate 20 with a relaxed seal 11 at a casing 3,4. The soldering material 9 contains globular spacers 10.

Figure 2 demonstrates the downward movement x_1 of the upper part 3 of the casing, a lowering of the chip 1 side stably held and the compression of the seal 11 up to where the globular spacers 10 limit the downward movement and the position the chip 1 is fixed (soldering phase).

Figure 3 illustrates the upward movement x_2 of the chip 1 with soldered substrate 20 and the cooling 5 under the substrate, with relaxing seal 11. The position and the spacing of the chip 1 of the substrate 20 remain unchanged.

The soldering process begins in figure 1 by inserting of the circuit card 20 on the heating plate 4. There the circuit card is attached firmly so that good heat conduction is made possible. On the circuit card 20 the solder 9 is applied with non-melting particles 10 by means of screen printing or preforming. The heating plate 4 brings the circuit card 20 depending on the base material

in some seconds up to some 10 seconds to the soldering temperature. During this time period inert gas can be injected into the chamber 30 formed between upper part 3 and lower part 4 for the reduction of the oxidizing. The very small volume permits achieving small remainder oxygen contents by small gas volumes.

Whether inert gas must be used depends on the soldering temperatures and the surfaces of the soldering partners. The short soldering process times that are possible with this method (approximately 60sec in contrast to 1800sec in the prior art) reduces already the danger of the oxidizing substantially. In many cases therefore an inert gas atmosphere can even be dispensed with entirely which improves the cost-efficiency of the process further.

In the second process step in accordance with figure 2, by turning on the vacuum V, the cover 3 together with the of chips 1 are slowly pressed onto the circuit card 20 that has meanwhile been covered with the liquid solder. By means of temperature resistant silicon suction units 2b the silicon chips 1 that are held in a vertical direction slightly elastically or resiliently at the cover are pressed by the increasing vacuum onto the circuit card 20. The controlled vacuum provides for slow and cavity-free placement of the chips 1 by means of the described spacers on the substrate 20. The chips are permanently laterally guided by the cover and held and cannot float away. The positioning accuracy is improved.

In the subsequent third process step in accordance with figure 3 the still liquid solder 9 is cooled down below the solidification temperature in a very short time (if possible under 10 seconds) by injecting cold gas B. Apart from the advantage that this enhances the crystalline structure, a very short process time results from the gas pad 5 that builds up underneath the chip and the substrate 1, 20 and raises these resulting in an enhanced cooling process.

The cover 3 has a receiving device 2 for at least one, preferably many chips 1 in the placing positions (for example a silicon mat with holes 2c or small suction units comprising interior channels 2c). The heating plate 4 with at least one opening 4c for injecting the cooling agent and an apparatus for placing the cover 3 and for loading the heating plate with the circuit card 20 are provided in addition. The latter apparatus can be a handling mechanism, for example a Scara robot, providing the necessary handling action.

A typical process cycle in a manufacturing process for manufacturing of substrates carrying soldered on power semiconductors is:

1. Placing of the printed circuit board 20 on the heating plate (approx. 250 degrees Celsius).
2. Sucking on the power semiconductor 1 by means of vacuum V1 from a placing nest with the "cover" as upper part 3 and side stable mounting plates for the several chips 1, wherein these are positioned in vertical direction flexibly

or resiliently, for instance over a silicon mat or single (individual) suction units 2.

3. Placing of the cover 3 over the printed circuit board (mechanically centered), in order to form a vacuum area 30 sealed along its circumference.

4. Flushing with inert gas.

5. Turning on the vacuum V2 after reaching the melting temperature of the solder 9 and evacuation in the vacuum area 30 (soldering area).

6. The cover together with chips is in a laterally fixed manner guided and lowered by means of the vacuum V2 between the heating plate 4 and the cover 3 into the liquid solder. No lateral movement of the chips happens during the vacuum-forced sucking on of the cover, at a maximum when pressing of the chips an elastic component in moving direction might add that presses the chips 1 against the globular spacers 10 in the solder and therefore forms over a large surface area an equidistant distance of the semiconductor chips without damaging these.

7. Soldering.

8. Cold gas B is injected underneath the circuit card thus the circuit card is cooled on a gas pad 5. Simultaneously, the vacuum V2 is terminated in the soldering area 30 continuously and the cover 3 with its sidewalls 3a, 3b moves away continuously from the heating plate 4 into a final position, resuming the position prior to switching on the vacuum. The chips 1 are moved together with the substrate 20 soldered thereto. Also, the substrate is lifted off the heating plate 4.

9. Lifting off the cover with soldered circuit card 20 and releasing the power semiconductors with circuit card (substrate) 20.

As the basic general design, the cover 3 in the figures is drawn as a hood with middle cover section 3a and side flange sections 3b that are in a temperature-proof manner via a circumferential elastic sealing 11 in sealing contact with the heating plate 4. The elastic sealing lip 11 allows a motion of the cover 3. It can move, caused by the vacuum in the soldering area 30, upwardly and downwardly, that motion being used for pressing the power chip 1 into the solder 9 comprising the globular parts 10 and can serve for lifting of the soldered chips together with the circuit card.

The chip 1 is in figure 1 held by means of a single suction unit 2, still above the solder 9 that has been heated up already. The single suction unit consists of a cylindrical section through which a middle channel 2c is guided connecting to a widened suction space by means of which the chip is sucked on. A circulating fetching claw being in a sealing connection with the chip is dimensioned such as to fit to the dimension of the chips 1. The fetching claw 2b has essentially a conical shape and extends in a very flat shape. The mentioned channel 2c in the cylindrical body opens into an opening 3c in the cover part, allowing to apply the vacuum for holding the chips 1 from the outside and releasing said vacuum.

Figure 2 illustrates the step of pressing the power semiconductor 1 into the liquid solder, wherein the globular spacers 10 define the specific spacing between the semiconductor 1 and the substrate 20. The single holding unit 2 positions the chip 1 in a side stable manner that can be held with slight resilience in vertical direction, either by holding by means of a spring or by providing supporting silicon mats or silicon disks between its cylindrical body and the cover 3a.

In figure 2, the downward movement of the cover is denoted with reference numeral x_1. In contrast to figure 1, the seal direction 11 is compressed in relation to figure 1, providing simultaneous sealing. The soldering area 30 is subjected to vacuum V2. Only by releasing of this vacuum in accordance with figure 3, the cover 3 lifts itself up as demonstrated by the direction of motion x_2.

Both movements are pure axial movements. Together with laterally stable holding of the chips 1 at the upper section pressing of the chips 1 into the solder 9, 10 is achieved, wherein a "floating" is avoided.

The gas B flowing in through a channel 4c provided in the bottom part (in the heating plate 4) provides for an even and safe cooling of the chip 1 over the substrate 20. The substrate 20 floats thereby on a gas pad, but it is also simultaneously held by the holder 2, over the solidifying solder 9. The supply of the cooling gas B simultaneously release the vacuum V2, while the vacuum remains V for holding the chip 1, now with the substrate 20 soldered to

the chip, until the cooling by the gas B has been sufficient in order to solidify the solder safely and completely.

Not shown is the removal of the finished soldered chip 1 - or of several chips 1 with exactly defined spacing on the substrate 20 - for the purpose of which the cover 3 is lifted up or the heating plate 4 can be laterally shifted, with it dragging along the gasket 11.

The invention relates to a process for soldering large surface semiconductor chips on a substrate (20), wherein a vacuum (V2) in a soldering area (30) moves an upper part (3) in relation to a lower part (4) and wherein the chips are held side stably at the upper part (3), wherein one or more chips (1) are pressed into the heated solder (9, 10), as well as an apparatus for conducting said method. Furthermore solder material is provided for attaching said large semiconductors chips (1), in particular power semiconductor chips, comprising a solder component (9) melting at a melting temperature and a multiplicity of grains (10), which are resistant to the soldering component and have a melting temperature that is higher than the melting temperature of the soldering component (9).

Patent claims

1. Process for soldering (9,10) of at least one semiconductor chip (1) having a surface area to a substrate (20), wherein

(a) by means of a vacuum (V2) in a soldering area (30) an upper part (3) is mechanically centered and moved (x_1, x_2) in relation to a lower part (4) while the substrate (20) is arranged on the lower part (4);

(b) the at least one semiconductor chip (1) is held during the relative movement at the upper part (3) in a side stably manner and pressed into the heated solder (9,10).

2. Process according to claim 1, wherein the at least one semiconductor chip (1) having a surface area is a large surface area power semiconductor.

3. Process according to one of the preceding claims, wherein the soldering area (30) is formed by a hood-like upper part (3; 3a, 3b), the side walls (3b) of which compress a compressible sealing ring (11) under influence of a vacuum to the point when the at least one semiconductor chip (1) reaches its soldering position with a defined spacing will from the substrate (20).

4. Process according to one of the preceding claims, wherein prior to soldering of the solder (9) onto the substrate (20) the soldering area (30) is flushed or rinsed with an inert gas.

5. Process according to one of the preceding claims, wherein after lowering of the at least one semiconductor chip (1) into the solder (9, 10) a cooling gas (B) is pressed from underneath (4c) against the substrate (20) in order to form an evenly cooling air cushion (5).

6. Process according to one of the preceding claims, wherein the substrate (20) is attached in a fixed manner on the lower part (4), in particular on a heating plate arranged on it, before the relative motion begins, wherein a lateral movement of upper part and lower part (3,4) is prevented.

7. Process according to one of the preceding claims, wherein the at least one semiconductor chip (1) is held in vertical direction flexibly, in particular resiliently in a spring like manner.

8. Process according one of the preceding claims, wherein the mechanically centered motion is a permanently laterally guided or held downward movement of the upper part in downward direction onto the vertically motionless lower part (4), at least during the soldering phase of the process.

9. Process according to one of the preceding claims, wherein it is prevented at least during their relative movement in a vertical direction that the upper part and the lower part (3,4) move laterally with respect to each other, wherein in particular a lateral movement during removal of the semiconductor (1) soldered on the substrate (20) is allowed.

10. Apparatus for carrying out the process according to one of claims 1-9, the apparatus comprising:

(a) an upper part (3; 3a, 3b) with a receiving means (2) for semiconductor chips (1) in a feeding positions;

(b) a means for positioning the upper part (3) and for a previous positioning of a flat lower part (4) comprising a substrate (20);

characterized in that

(c) the lower part is designed as a heating plate (4) with at least one opening (4c) for injecting a cooling agent (B);

(d) the upper part (3) comprises side flange sections (3b) that are by means of a temperature-proof flexible seal (11) elastically in connection with the heating plate (4), in order to permit a relative motion (x_1, x_2) of the upper part (3) in relation to the heating plate (4).

11. Apparatus according to apparatus claim 10, wherein the receiving means (2) comprises a silicon mat having holes (2c, 3c) or consists of small individual suction units for holding or laterally guiding the chip or the chips (1) permanently during the soldering process.

12. Apparatus according to one of the preceding apparatus claims, wherein the soldering area (30), that is formed by the upper part (3) and lower part (4) has a small volume by having a horizontal extension that corresponds approximately to the size of the substrate forming the circuit card (20) and extends in a vertical direction only slightly higher as required for accommodating the substrate (20), the solder layer (9, 10) and the chip (1) as well as the chip holder (2; 2a, 2b, 2c).

13. Apparatus according to one of the preceding apparatus claims, wherein one or two openings for flushing with and removing or rinsing with an inert gas open into the soldering area (30).

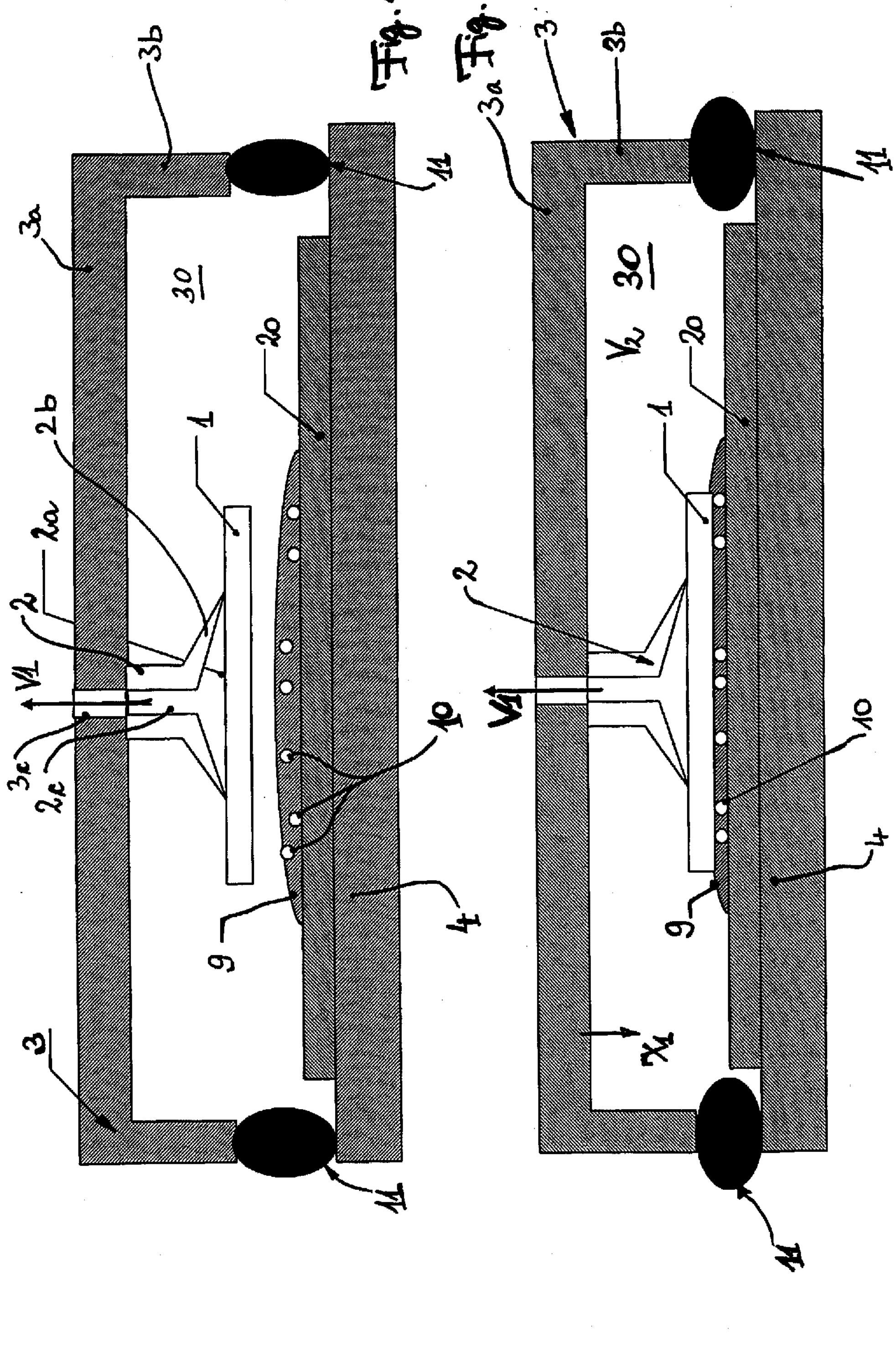
14. Soldering material (9,10) for attaching large semiconductor chips (1), in particular power semiconductors (1), according to one of the claims 1 to 10 or in an apparatus according to one of the claims 10 to 13, wherein the solder comprises one soldering component (9) that melts at a melting temperature and comprises a plurality of granules (10) that are resistant in relation to the soldering component and have a melting temperature that is higher than the melting temperature of the soldering component (9) and have a diameter that is determined by the spacing to be achieved between the substrate (20) and the semiconductor chip (1) to be soldered thereto.

15. Soldering material according to claim 14, wherein the melting temperature of the granules (10) is substantially higher than the melting temperature of the soldering component (9).

16. Soldering material according to claim 14 or 15, wherein the granules are shaped as globules, and are in particular made of glass, copper or silicon.

17. Soldering material according to one of claims 14 to 16, wherein the percentage of granules is smaller in comparison to the soldering component, in particular the granule percentage is below 20% by weight.

Fig. 1 Fig. 2



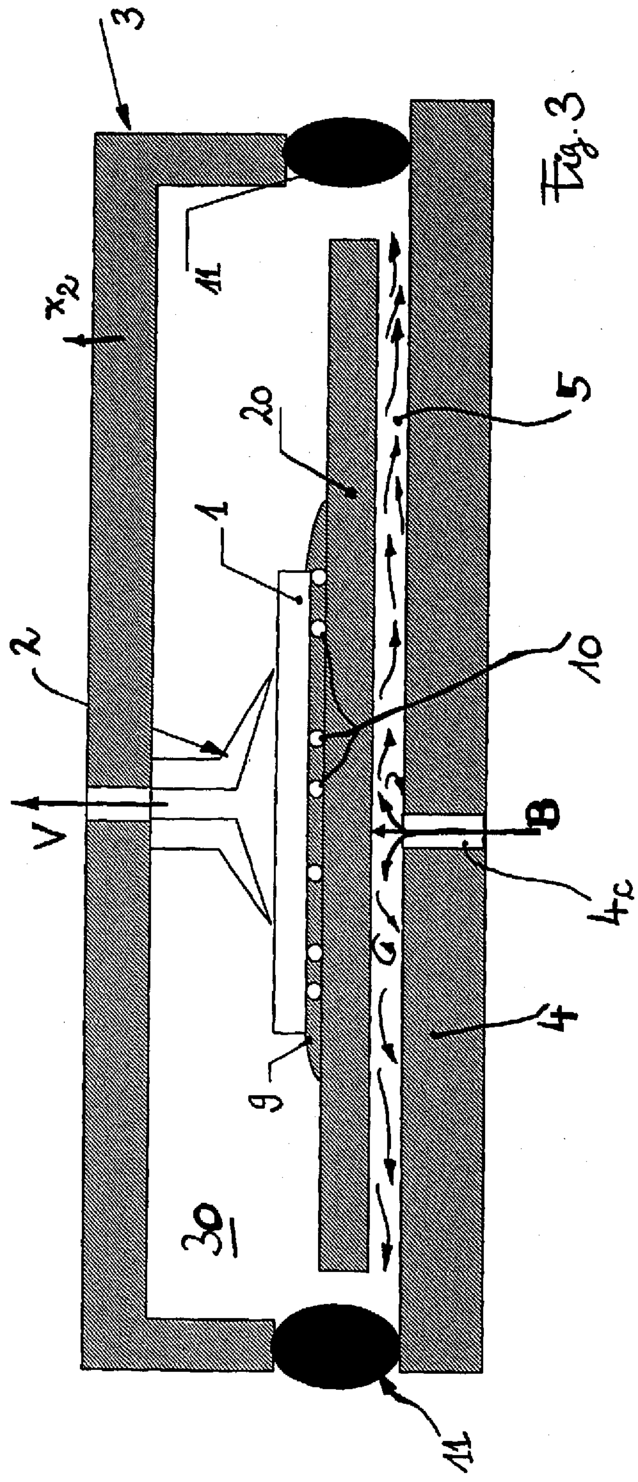


Fig. 3